the Signal Corps. These observations show air currents increasing in intensity with increasing altitude and approaching the huge speed of 100 miles per hour. Such speeds are perhaps exceptional but not at all uncommon. The pilot balloon mentioned in section 3 above, traveled from Omaha to Virginia at an average speed of 30 miles per hour, the average height being 18,000 feet. On November 6, 1918, at Chattanooga, Tenn., a velocity of 154 miles an hour at an altitude of 28,000 feet was observed by one of the meteorological units of the Signal Corps. These facts bring out the importance of a forecast of such currents for the purpose of long flights. A flier aided by such a wind as that last mentioned would move toward his objective 2×154, or 308 miles an hour more rapidly than if he were opposed by it. When it is recalled that the aviator above the clouds has no means of knowing anything about the motion of the air in which he flies it will be seen that it is of the greatest importance to him to know the nature of the currents at different levels. Table 2 furnishes a very typical illustration of this importance.

TABLE 2.

Altitude.	Wind direction.	Wind velocity.
Meters.		*Miles per hour.*
Surface	nw.	2.2
500	e.	5.8
1,000	e.	8.3
2,000	ne.	5.4
3,000	w.	5.4
4,000	nw.	24.6
12,000	nw.	49.2

From the above data it is evident that on this occasion an aviator flying toward the west should fly at an altitude of 1,000 meters, while an aviator flying toward the east should fly at an altitude of 4,000 meters or more.

In order to meet the obvious need of the aviator for a knowledge of the upper-air currents, the Signal Corps in the summer of 1917 undertook for the first time in history a general program of systematically mapping the upper-air currents of the United States, the Atlantic, and western Europe in aid of aviation and particularly with reference to trans-Atlantic flight. By the fall of 1918 26 upper-air stations carefully distributed over the United States were in full operation in place of the 1 station which had existed before the war. From these stations reports are telegraphed twice daily to the Weather Bureau in Washington. From the pilot-balloon observations charts are constructed showing the wind direction and velocity at the various levels; for instance, one chart shows the wind direction and velocity near the ground, another chart shows the wind direction and velocity 500 meters above the ground, and additional charts show the wind direction and velocity at the following levels: 1,000, 1,500, 2,000, 3,000, and 4,000 meters above the ground.[1] The forecaster at Washington has the various charts before him, showing wind and weather conditions prevailing over the United States, within an hour and a half after the observations are made. From these charts he prepares the forecast of weather conditions for the various sections of the United States, and at the same time prepares a statement of the wind and weather conditions at various altitudes along the various air routes for the use of aerial navigation. This service is already being used by the Aerial Mail Service. It is also used by the military fliers, as is evidenced by telegraphic requests received at various military meteorological stations for special reports on the weather and wind conditions when long-distance flights are contemplated.

The problem of exploring the upper-air currents over the Atlantic was at first thought insoluble on account of the absence of fixed bases, but the success of the Meteorological Service in developing its long-range propaganda balloons has now made possible the mapping of the upper-air highways across the Atlantic, for arrangements are being made to send up both from coastal stations and from trans-Atlantic steamers these long-range balloons designed now for from 2,000 to 3,000 mile flights, and adjusted to maintain a constant altitude and to drop in western Europe their records of average winds in these heretofore unchartable regions. The importance of this work for the future of aviation needs no emphasis.

The success which the Meteorological Service has attained would have been wholly impossible had it not been for the intimate and effective cooperation which has been extended to it in all of its projects by the United States Weather Bureau through its chief, Prof. C. F. Marvin, and its entire staff. The chief credit for the work abroad should go to Lieut. Col. William R. Blair, commissioned from the Weather Bureau for the observational work with the A. E. F. For the success of the service in this country Capt. Sherry and Lieut. Waterman have the chief responsibility. Capt. Murphy and Prof. Fassig have, however, contributed very important elements.

[1] See fig. 3, p. 220, below.

THE MILITARY METEOROLOGICAL SERVICE IN THE UNITED STATES DURING THE WAR.

By BERTRAM J. SHERRY, Captain, Signal Corps, and ALAN T. WATERMAN, First Lieutenant, Signal Corps.

[Dated: Washington, D. C., May 15, 1919.]

Previous to the beginning of the war in 1914 no nation, with the possible exception of Germany, had made provision for meteorological work as used in modern warfare. It is true that surface meteorological observations were made at some of the military posts, but no systematic meteorological work was attempted nor had any upper-air observations been made with a view to providing the Air Service and the Artillery with necessary meteorological data. In the United States the Weather Bureau has always maintained an efficient civilian meteorological service and has accumulated an enormous amount of data, both of surface and of upper-air meteorological conditions, and had not these data been available during the war a great many aviation and artillery problems would have been much more difficult.

With the present development of aviation it becomes highly desirable that a more intimate knowledge of upper-air conditions be obtained. The development of modern artillery makes it necessary that certain corrections for variation from normal in the atmospheric conditions be incorporated in artillery range tables. For instance, it has been found that in firing the 75-mm. gun at a target 7,000 meters away an opposing wind of 10 meters per second will cause the projectile to fall nearly 400 meters (a quarter of a mile) short of the target. In order to make the proper correction to the aim in artillery fire it is necessary to know the wind direction and speed at various altitudes up to the maximum height reached by the projectile. In the case cited above this would be approximately 2,000 meters. Besides making corrections for wind, it is necessary also to make allowance for variations in the density of the air, and in some instances this correction is quite as important as that for wind. The use of gas in the war made it important that close attention be paid to wind direction and speed. In fact, the operations of all branches of the military service were to a considerable extent dependent upon weather conditions, and consequently weather forecasts were in demand.

It was some time after the declaration of war before England and France had meteorological services operating with their armies.[1] When the United States entered the war a few months elapsed before it was decided that the United States would put a large army on the battle front. When it became evident that such an army would be sent to Europe it was also apparent that a military meteorological service would be necessary as a part of this army. The Chief Signal Officer of the Army directed that a Meteorological Service be organized within the Signal Corps, under the immediate supervision of Lieut. Col. R. A. Millikan, Chief of the Science and Research Division of the Signal Corps. Dr. W. R. Blair and Mr. E. H. Bowie, both of the U. S. Weather Bureau, were commissioned as majors in the Signal Corps and sent overseas to investigate and report on the needs of the American Expeditionary Army for meteorological data. It was the intention at first to provide a meteorological service for duty with the American Expeditionary Forces only. However, it was soon found that it would be necessary to organize a meteorological section for duty in the United States to furnish data to the various military posts for the benefit of Ordnance, Air Service, and Artillery units in training, and in the development of problems in connection with their work. From cablegrams received from Gen. Pershing it was determined that approximately 21 officers and 300 enlisted men would be required for duty overseas. Approximately 15 officers and 200 men were required to meet the needs for military meteorological work in the United States.

The number of men with the qualifications desired was not available, and it was necessary to take men having satisfactory educational qualifications and give them additional training in meteorology and aerology. The first 150 men obtained were sent to various Weather Bureau stations in the United States for training in meteorology. After a short period of training nine of these men were sent to Fort Omaha, and in November, 1917, the first military meteorological and aerological station was established at that place. A school of meteorology was opened at College Station, Tex., with Dr. Oliver L. Fassig as Chief Instructor, where approximately 330 men were given training in meteorology and aerology.[2] Men were sent overseas in groups of 50 until approximately 300 men had been sent.

In the United States 37 military meteorological stations were established, equipped with instruments and personnel for furnishing meteorological data to other branches of the Army. Most of these stations were at military posts and were established at the request of some branch of the military service. The stations at the Aberdeen Proving Ground, Aberdeen, Md., and at the Sandy Hook Proving Ground, Sandy Hook, N. J., were established for furnishing accurate data of surface and upper-air conditions to the Ordnance for use in connection with range-firing experiments. At both of these stations the Meteorological Section of the Signal Corps cooperated with the Ordnance in developing the first range tables constructed by the United States Army in which corrections were to be incorporated based on actual observations for variations from normal air density, wind direction, and speed along the trajectories. For the purpose of instructing student officers and men in the use of these tables, military meteorological stations were established at the Coast Artillery School, Fort Monroe, Va., the School of Fire, Fort Sill, Okla., and the Field Artillery Firing Centers at Camp Jackson, S. C., and Camp Knox, Ky. Meteorological stations were also established at Hazelhurst Field, N. Y.; Ellington Field, Tex.; Kelly Field, Tex., and a number of other flying fields in various parts of the country, for the purpose of supplying information concerning both surface and upper-air conditions for use in connection with the training of student aviators and also in connection with cross-country flying. For the purpose of furnishing meteorological data to be used in connection with the training of balloon pilots and observers for both observation and free-balloon work, stations were established at the Army Balloon Schools at Fort Omaha, Nebr., and Arcadia, Cal. Meteorological stations were established at a number of other points in the United States for the purpose of furnishing data to other branches of the Army, and many of the stations, including some of those named above, furnished data to two or more branches of the military service.

In organizing the Meteorological Service the Signal Corps was confronted with the project of creating what was in many respects an entirely new service for the Army designed to supply the military organization with complete and up-to-date meteorological information, and this as promptly and efficiently as possible. The undertaking necessarily involved, in addition to consideration of methods employed by former or present meteorological organizations, actual experimental investigation, and the development and standardization of new methods. Inasmuch as the U. S. Weather Bureau constituted an efficient organization for dealing with surface meteorological data, and as a number of the personnel of that department were available for the Service and familiar with its methods, it was decided, as far as surface observations were concerned, to adopt as standard practice the methods and type of equipment used by the Weather Bureau.

The question of the proper units to be employed in recording observations and in issuing reports required consideration, and the metric system was decided upon as being the simplest and also that required for work overseas. For serving the various military branches in the United States, however, a number of different units were in use, so that it was impracticable to adopt a single system which would conform to all requirements. In this country, therefore, observations were recorded and station records were kept in the metric system, and reports were furnished in any units desired locally.

The main outstanding problem was that of developing suitable methods for obtaining data concerning the upper air. The methods which had previously been employed for this purpose were: (1) The use of sounding balloons, (2) manned (free) balloons, (3) observation (kite) balloons, (4) kites, and (5) airplanes. All of these permit the procuring of complete upper-air data (temperature, pressure, humidity, and wind). The sounding-balloon method consists of attaching recording apparatus to a balloon of approximately 7 feet diameter

[1] For an account of the British service, see "Meteorology during and after the war," MONTHLY WEATHER REVIEW, February, 1919, 47:81-83.

[2] See "A Signal Corps school of meteorology," by O. L. Fassig, MONTHLY WEATHER REVIEW, December, 1918, 46: 560-562. Some account of the methods of teaching at this school are given in "Collegiate instruction in meteorology," by C. F. Brooks, ibid., pp. 554-560.

inflated with hydrogen and allowed to ascend. When the balloon bursts or loses its gas the apparatus descends on a parachute. For military purposes, the sounding balloon is evidently out of the question on account of the delay and uncertainty in recovering the recorded data. The manned balloon is debarred for the same reason, and also because of the limited range of observation. Observation or kite balloons may, of course, be employed. There are serious limitations to their use, however, such as the expensive and elaborate equipment, the low altitudes attained, and the danger in launching in a high wind. Kites are excellent, but require considerable equipment, and render aviation unsafe in their neighborhood on account of the kite wire. They also are not readily launched in very light winds. Nevertheless, they are desirable equipment for permanent meteorological stations where accurate and complete data aloft are required. The last-named method, by airplane, is entirely practicable and has been employed by the Signal Corps at the Aberdeen Proving Ground. Recording apparatus is carried by the airplane, which flies steadily for a certain length of time at each altitude for which data are desired. An alternative, and the usual method, is to carry non-recording instruments, which are read by an observer at the altitudes desired, and whenever any unusual condition is experienced. The use of an airplane for obtaining data aloft has the disadvantage that it is impracticable to determine the wind velocity accurately. More than 350 airplane meteorological flights have been made at Aberdeen, usually to 10,000 feet.

Such complete knowledge of upper-air conditions as will admit of the computation of densities aloft is desired by the Artillery only, whereas a knowledge of the wind aloft is extremely valuable to the aviation and balloon services as well as to the Artillery. There are several simpler methods available for ascertaining only wind speed and direction: (1) Observations on pilot balloons, (2) observations on movement of the smoke of anti-aircraft shell bursts, and (3) sound-ranging on pilot balloons carrying a train of explosives.[3] Inasmuch as a knowledge of the upper winds is what is mainly desired by the Army, the development of efficient methods for obtaining these data was of foremost importance. Since the two latter methods mentioned depend upon the assistance of two other branches of the Army—the anti-aircraft and the sound-ranging services—it was decided to use the first, namely, that by observation on pilot balloons. This method was soon found to be most satisfactory, and, accordingly, an important undertaking of the Signal Corps was the development of practicable, speedy, and efficient means of making upper-air observations with pilot balloons, and of computing and tabulating therefrom data in a usable form. Practicable field methods were soon devised, and these have continually been improved until at the present time a highly efficient system is in operation. The disadvantage of the pilot-balloon method of observation is the fact that the observation is limited to the height to which the balloon can be seen, and is therefore restricted in altitude on cloudy days. On clear days, however, it is far more efficient than other methods, as is evidenced by the fact that observations to a height of about 12 kilometers are by no means unusual. The record altitude reached in this service by this means is 20 kilometers,[4] and balloons have been seen to a horizontal distance of 70 kilometers.

Although the pilot-balloon method of determining wind aloft was not new to meteorologists, it had only been applied in connection with upper-air research, in which the speed of computing results and the transfer of the equipment was of secondary importance. The Signal Corps immediately undertook the development of practicable military methods, which require principally speed of operation and portability of equipment. Briefly, the operation consists in allowing a pilot balloon to ascend freely. The balloon in its upward course is carried along horizontally by the wind and is a most sensitive indicator of wind velocity. It may be viewed through two theodolites placed at the ends of a measured base line, and simultaneous reading of elevation and azimuth angles may be made at regular intervals. By triangulation the actual path of the balloon relative to the earth may be calculated. From the horizontal projection of this path, which is plotted for points taken at known intervals of time, the average wind velocity (speed and direction) over any interval may be obtained at each respective altitude. An alternative method, which is more easily adapted to military use, employs only one theodolite, and assumes a known uniform rate of ascent of the balloon. The computation can then be made as before, much saving is effected in personnel, equipment, and portability, and the method is admirably adapted to rapid field work.

A requirement for either the one or the two theodolite method is a satisfactory type of balloon. The balloon should admit of high inflation and possess minimum weight in order to reach the greatest possible altitude before being lost to sight. The rubber should be so cured as to retain its elasticity for a moderate period, should allow only slow diffusion of hydrogen through its walls, and should be so colored as to be visible against the different backgrounds encountered. All balloons should be of the same shape in order to simplify the calculation of rate of ascent. Much attention has been given to these points, and after careful testing it has been found that the most satisfactory balloons are of pure rubber, and of approximately spherical shape when inflated. (See frontispiece.) These balloons are used in two shades—uncolored, for use against a clear sky, and dark red, for a cloudy or hazy sky. A balloon which will inflate to a maximum diameter of 80 centimeters should weigh from 20 to 30 grams, and one inflating to a maximum diameter of 120 centimeters, approximately 50 to 60 grams. The manufacture of satisfactory balloons of larger size than the last named (about 9 inches in diameter deflated) appears to be very difficult.

A special type of theodolite (see fig. 3, opposite p. 207) was designed by Dr. W. R. Blair while connected with the U. S. Weather Bureau. This instrument, with a few minor alterations, has been used exclusively in this country. Its essential feature is the use of a right-angled prism at the center of the telescope tube, whereby the observer is able to look always in a horizontal plane while sighting upon objects in space.

Although the single-theodolite method of observation is more readily adaptable for field use than the two-theodolite method, the accuracy of its results is dependent upon the accuracy with which the altitude of the balloon is known. With the formulas for rate of ascent now in use this accuracy is not great. It was therefore found desirable to maintain meteorological stations for two-theodolite observations at posts where the greatest degree of accuracy was desired, as, for instance, at proving grounds where investigations were conducted concerning the factors which influence the flight of projectiles. Considerable work was necessary in order to bring this more cumbersome method to a point where

[3] For further details see MONTHLY WEATHER REVIEW, Feb., 1919, 47: 70.
[4] See graph No. 7 in fig. 2, p. 213, above

the necessary speed of operation would be attained. A large number of devices were designed to gain this end. Special slide rules and alignment charts have been made for solving the trigonometric formulas involved in determining the position of the balloon from time to time. After the latter is known the path of the balloon may be readily plotted and the wind velocity obtained at any altitude. Methods have been devised for computing the wind velocity without graphical aid, but they have been found not to compare favorably with graphical methods.

These latter methods operate on the principle of duplicating on a small scale the configuration of the system (balloon, base line, and two theodolites) by means of plotting board and apparatus. For finding the altitude of the balloon when the horizontal projection path is known, an ordinary slide rule may be used, or this, too, may be solved by graphical means. Plotting boards for two-theodolite work, differing slightly in detail, were developed independently at Signal Corps stations at Aberdeen Proving Ground, Fort Monroe, Fort Sill, Hazelhurst Field, and Ellington Field. A form which seems to be as direct as any that can be devised is illustrated and discussed on page 222 below. It is necessary for rapid work that telephonic communications be established between the observing stations and the plotting room. Each observer and each plotter wears a telephone head set. (Fg. 1, frontispiece.) The readings are called in from the observing stations to the plotting room as soon as taken; thus the charting goes on as fast as the observation progresses. To insure simultaneous readings, at each of the two theodolites suitable signals are given the observers by means of a standard Signal Corps time-interval apparatus and time-interval bells, or these signals may be sent by means of a buzzer on the telephone circuit. In this way the computation of the wind velocity may be made to keep pace with the observation. The two-theodolite method of observation is, of necessity, available for use at more or less permanent stations only.

In regard to the simpler, single-theodolite method, the first requisite was a formula for the rate of ascent of the balloon in order that the altitude might be known at each reading taken. In other words, it was necessary to predict from known measurements of a given balloon, as, for instance, its diameter, weight, and lifting power, what the rate of ascent would be. Some general deductions regarding the rate of ascent of pilot balloons have been given by Mallock[5] from theoretical considerations. In his paper it is shown that at first, leaving out of consideration the loss of gas, a balloon will ascend with a slight positive acceleration, which later decreases to zero and then becomes increasingly negative until the maximum altitude is reached. This behavior is exhibited to some extent by large sounding balloons; but they are inflated to a much less degree than the small pilot balloons in the attempt to reach high altitude rather than to gain a rapid ascensional rate. As a matter of fact, practically all the pilot-balloon observations of the sort conducted by the Signal Corps show a rate of ascent which is very nearly uniform up to altitudes of certainly 10 kilometers and in many cases much higher. The matter of the rate of ascent is also treated by Millikan[6] and, as shown by him, for moderate altitudes the loss of gas by diffusion just compensates for the positive acceleration that would otherwise occur.

This fact has been taken advantage of in most work that has been done on the rate of ascent of pilot balloons to deduce a partially theoretical formula, which will satisfy experimental results. It is assumed that since the rate of ascent is constant a formula will apply which holds for the case of a balloon moving through air of constant density and under the influence of a force equal to its lifting power in such an atmosphere. To enter into the subject fully would properly require a special article. It may be stated briefly, however, that the two best known formulas derived in this way are those of Dines[7] and Hergesell.[8] They are respectively:

$$V=K\frac{l^{1/2}}{L^{1/3}};\quad V=f\left(\frac{l}{L^{2/3}-0.8L^{4/3}}\right)$$

where V represents velocity; l, the "free lift," represents the actual lifting power of the balloon, i. e., the attached weight it will support; L, "the total lift," is the free lift plus the weight of the balloon; and K is a constant. Variations in density of the air introduce negligible errors in comparison with those due to other causes.

A large amount of investigation has been conducted by the Meteorological Section, Signal Corps, with a view to solving this problem. At the beginning it was found that the formulas of Dines and Hergesell did not agree with actual free-air observations made by the Signal Corps, and at Fort Omaha in December, 1917, a purely empirical formula was deduced, which was used for a short time. Its use is restricted to balloons of total lift in the neighborhood of 80 grams only, and it is accurate for the range for which it was designed. It was soon discarded, however, on account of its restricted range and applicability to balloons of low inflation only.

From the records of about 5,000 pilot-balloon observations made with two theodolites at various points in the United States, 1,000 have been selected because of their length and accuracy. These have been tabulated and examined carefully. It is found that the results obtained do not agree with the results of either Dines or Hergesell for the type of balloons employed. In addition, experiments in charge of Lieuts. W. S. Bowen and H. H. Anderson were performed at the Signal Corps School of Meteorology, College Station, Tex., in which balloons of various diameters with different weights attached were dropped from the interior dome of a high building and the rate of descent directly observed. On the basis of these experiments and the accumulated data obtained from two theodolite observations mentioned above the following formula was produced:

$$V=71\left(\frac{l}{L^{2/3}}\right)^{5/8}=71\left(\frac{l^3}{L^2}\right)^{.208}$$

The accuracy of any formula yet devised leaves much to be desired, as the velocity of ascent may be relied upon only to an accuracy of 5 per cent or occasionally 10 per cent. The formula developed by the Signal Corps has been demonstrated to be more accurate for the work in hand than that of either Dines or Hergesell.

Tests on the internal pressure of balloons used show that it at first decreases with increasing inflation, later becomes very nearly constant (approximately 5 cm. of water) for a considerable range, and increases just before

[5] A. Mallock: Proc. Roy. Soc. v. 80, No. A541, June 10, 1908, pp. 530-534.
[6] R. A. Millikan: p. 211, above.

[7] Quart. Jour. Roy., Meteor. Soc. April, 1913, v. 39, pp. 101-107, and April, 1918, v. 44, pp. 131-133.
[8] Sixième Réunion de la Commission International pour l'Aerostation Scientifique, Monaco, 1909, pp. 86-103.

the bursting point is reached. The diffusion through the walls is rather an uncertain quantity, but averages about 4 to 6 per cent of the volume per hour.

To return to a discussion of the single-theodolite method of observation, where it is assumed that the altitude of the balloon at the time of taking each reading is known beforehand, and the only remaining quantity to be determined is the radial distance in a horizontal plane of the balloon from the starting point. This permits of ready calculation with an ordinary slide rule on account of the simple formula involved, viz:

$$\text{Distance} = \text{height}/\tan e;$$

where e is the elevation angle.

One successful method for single-theodolite work is to compute this horizontal distance by slide rule and then to chart the balloon's path on a simple plotting board provided with a scaled arm pivoted at the center of a 360° protractor. Another satisfactory method consists in the use of a similar board combined with a graphical altitude-finding device, the principle of which is the graphical solution of the above formula. Fully a dozen efficient plotting boards and methods have been devised by members of the Meteorological Section of the Signal Corps, which differ in details of construction but which fall under one of the two general classifications named above. That adopted by the Meteorological Service for general use is illustrated in figure 4. The observation point should be connected by telephone with the plotting room as in two-theodolite work and the time-interval system is also an advantage, though not essential.

An important feature of the meteorological work at Artillery stations consists in the calculation of the "ballistic" wind. Corrections for Artillery fire are made for variations of meteorological conditions from normal. The normal condition as to wind is taken by the Artillery to be "calm." Since the wind differs in speed and direction at different altitudes and since a projectile spends a different amount of time in each zone of altitude, it is necessary that these factors be taken into consideration. The "ballistic" wind is an imaginary wind, which would have the same deflective effect upon a given projectile as the total resultant effect of the varying winds which the projectile encounters during its flight. A projectile spends an increasing amount of time in each successive zone up to the maximum ordinate; in fact, about half the time of flight is spent above three-fourths of the maximum ordinate. The ballistic wind is, therefore, computed by finding the resultant of the true wind velocities for zones of equal altitude up to the height of the maximum ordinate, each taken with properly applied weighting factors. At Artillery and Ordnance stations the meteorological detachments are expected to compute this ballistic wind in connection with all balloon observations. Considerable work is here involved since, as a rule, a ballistic wind must be calculated for each different maximum ordinate; thus, frequently, from a single balloon observation the ballistic winds for 10 different maximum ordinates are required. Methods of calculation are in use in Signal Corps meteorological detachments which enable reports to be delivered on these ballistic winds at the completion of the balloon observation. In addition to the work of computing these data at all Artillery posts, at the Aberdeen and the Sandy Hook Proving Grounds meteorological detachments under the direction of Lieut. J. W. Howard, Signal Corps, cooperated with the Ordnance Department in examining the results of range firing under different meteorological conditions and in devising means of making the proper corrections.

A great variety of problems were undertaken by the Signal Corps, a number of which are briefly outlined below.

Upper-air data obtained by making simultaneous observations at Signal Corps stations in various parts of the country are telegraphed to the United States Weather Bureau at Washington, where upper-air forecasts are issued daily by the Weather Bureau regarding upper-air conditions likely to be encountered in flying over various parts of the United States. This work gives promise of being, in addition to its military value, of material assistance to the Aerial Mail Service and commercial aviation in the United States. Charts of winds at different levels above the surface over the United States, as observed on February 5, 1919, are shown in figure 3. For dynamical studies this usual method of mapping according to altitude above the observation point, gives way to that of mapping according to altitude above sea level.[9] In fact, for long distance flights, maps of this latter type are more useful to aviators than are those shown in figure 4, for the atmospheric pressure, rather than the configuration of the surface indicates (by altimeter) the elevation.

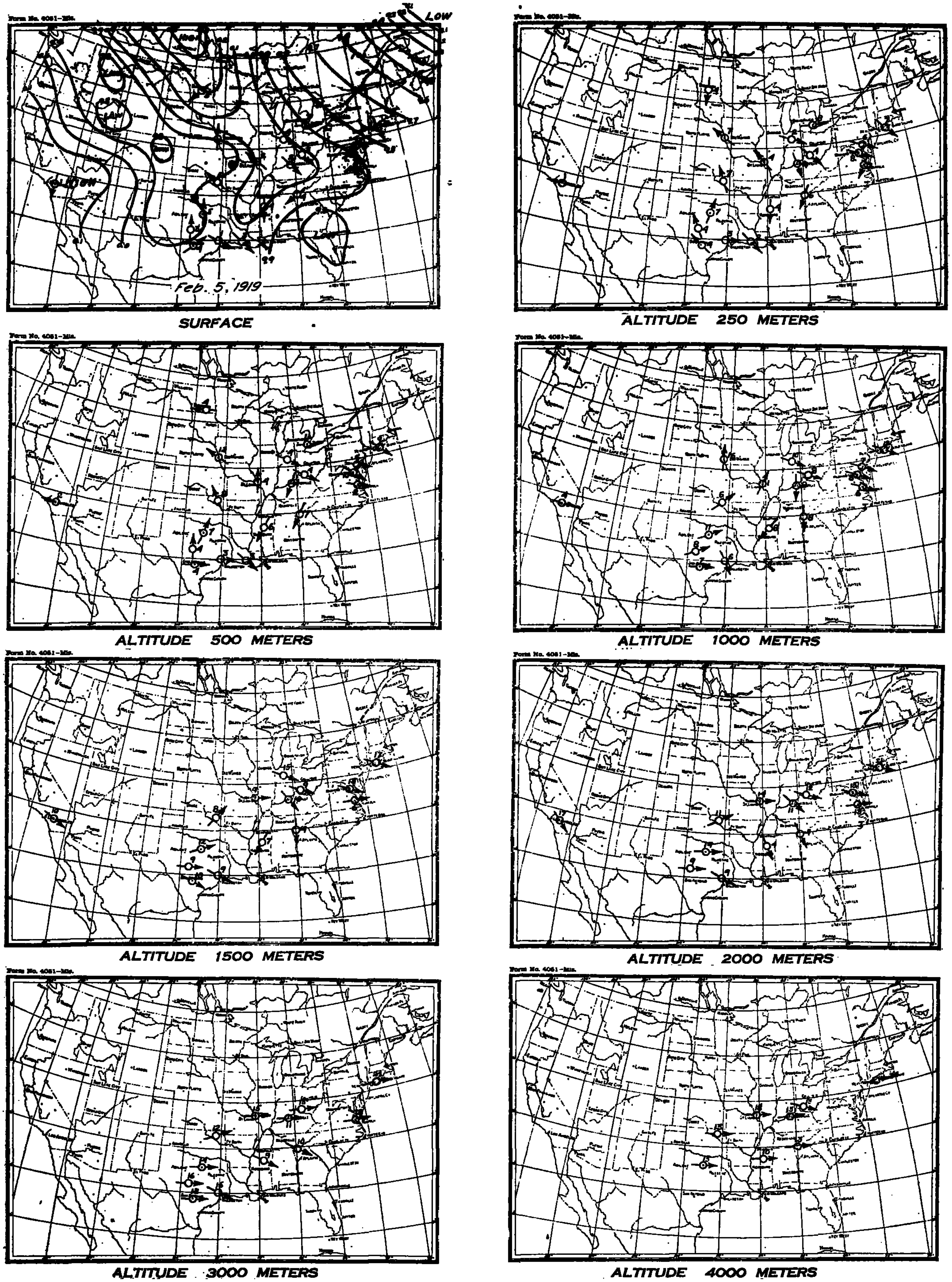
The question arose as to the area over which the results of a wind-aloft observation might be expected to hold. Although it was known that the upper winds are practically constant for a considerable range and that this is not true of the surface wind, an actual series of tests were conducted at Sandy Hook and at Aberdeen. Single theodolite observations were made simultaneously at Sandy Hook Proving Ground and at Long Branch, N. J., which are approximately 25 miles apart. Simultaneous observations were also made with two theodolites each at Aberdeen and Swan Point, Md., 26 miles apart, at opposite ends of the proving grounds. More than 100 observations were taken, and from the results it appears that between the stations at either proving ground the differences in the wind velocity at the same levels above altitudes of 500 to 1,000 meters were, almost without exception, less than 4 per cent. It was, therefore, concluded that the result of the wind-aloft determinations, can be relied upon usually for practically every purpose within a radius of 25 miles.[10]

A detail that was studied with interest was the effect of vertical convection currents upon the balloon as showing the magnitude of such currents and the height to which they are likely to ascend. Lieut. Tannehill has discussed some instances on pages 223–225, below. It was found that such currents are apt to exist from the ground to an altitude of about 1,000 meters, decreasing in intensity with altitude. As a general thing, during the daytime the balloon's rate of ascent is likely to be accelerated about 20 per cent for the first 300 to 400 meters of ascent, and then often diminished for the succeeding 100 meters, after which it becomes constant. More rarely the reverse is true, the balloon rising less rapidly at the start. Occasionally, pronounced convection is evident up to 3 kilometers, and at times indications of strong isolated ascending or descending currents may be found at altitudes up to 10 kilometers.

At the Signal Corps stations at the Army Balloon Schools at Fort Omaha and Arcadia, systematic observations from kite balloons were made on the visibility possible in different conditions of the atmosphere.

[9] Cf. Daily Weather Report, Upper-Air Supplement, Metl. Off., London: Morning, afternoon, and evening wind maps are published daily (since Apr. 1, 1919) for the surface, 1,000, 2,000, 5,000, 8,000, 10,000, 15,000 feet and upper-cloud, and lower-cloud levels.—ED.

[10] Such is not the case, however, with data *below* 500 meters at Coast Artillery stations, as indicated by Col. W. E. Ellis in discussing "Free-air data in the Hawaiian Islands, July, 1915" (MONTHLY WEATHER REVIEW, 1917, 45:52–55). Experiments with 12-in. shells indicated that weather conditions at the battery a little way inland do not show the conditions on the coast or out to sea.—ED.



MAPS SHOWING WIND DIRECTION AND SPEED AT VARIOUS ALTITUDES
ABOVE THE GROUND
FROM PILOT BALLOON OBSERVATIONS
WIND VELOCITY IN METERS PER SECOND BY SIGNAL CORPS ARROWS FLY WITH THE WIND

FIG. 3.—Winds Feb. 5, 1919. (The isobars on the first map are for inches pressure reduced to sea level. 2s and 3s have been omitted before 9.s and 0.s, respectively.)

Visibility charts were made twice daily showing (1) the extreme limit of vision, (2) and the limit of clear vision, in every direction from the observation point.

The question of night pilot-balloon observations was investigated at a number of stations. The various methods that have been employed to render the balloon visible at night are: (1) The suspension from the balloon of a small test tube filled with kerosene into the stopper of which a lamp wick is inserted, (2) a ball of tow bound with wire and saturated with kerosene, (3) a small electric flash light, (4) luminous paint, and (5) a small box constructed of tracing cloth containing a candle. In such devices the fire risk must be taken into account, in case the balloon bursts at a low altitude. The method used overseas was the last one named, i. e., the candle in a tracing cloth box, and this far it seems to be the most satisfactory method.

At Ellington Field, Tex., in cooperation with the Weather Bureau and the Engineer Corps, kite equipment was utilized to raise to altitudes of about 1,500 feet listening devices for detecting the approach of airplanes.

A large variety of charts and tables have been made for calculation of vapor pressure, relative humidity, dewpoint, air density, temperature correction for barometer, wind velocity from chart of balloon's course, rate of ascent of pilot balloons, ballistic wind, etc.

The methods in use for pilot-balloon work have been analyzed and studied, especially in regard to their degree of accuracy. In this connection, the following is of interest: For two-theodolite work a suitable plotting board will give results as accurate as the readings of the theodolites. For the altitudes and distances ordinarily reached in pilot-balloon work and with the present type of theodolite the most satisfactory length of base line is about 2,000 meters. When only two instruments are employed the general formulas for trignometric calculation of the balloon's position are:

$$d=\frac{b \sin B}{\sin(A-B)};\quad h=d \tan e \qquad (A)$$

where d equals horizontal distance from observation point (1).

h equals altitude above observation point (1).

b equals length of base line.

A equals azimuth angle at observation point (1).

B equals azimuth angle at observation point (2).

e equals elevation angle at observation point (1).

e' equals elevation angle at observation point (2).

Both instruments are set with zero azimuth along the base line and in the same direction.

This formula is impracticable when the balloon is nearly in a vertical plane through the base line, as the azimuth angles can not then be read with enough accuracy to avoid large errors in the calculation. In this case, the following formula gives more satisfactory results when the observing stations are at approximately the same altitude:

$$h=\frac{b \tan e \tan e'}{\sqrt{\tan^2 e-\sin^2 A \tan^2 e'} \pm \text{Co}^* \text{s} A \tan e'}$$

A more usable approximation of the latter formula is:

$$h=\frac{b \tan e \tan e'}{\tan e \pm^* \tan e'}$$

* The plus sign is used when the balloon is between the observing points; otherwise the minus sign is employed.

This latter formula is sufficiently accurate for azimuth angles less than 10° or 12°, which is the range at which formula (A) begins to break down. The difficulty observed in the use of formula (A) is also found in the use of a double-theodolite plotting board such as described, and in such a case it is customary to assume that the balloon is in a vertical plane through the base line and to use the two plotting arms for finding the horizontal distance and altitude by duplicating the base line and two elevation angles, rather than the two azimuth angles.

The accuracy of the single-theodolite method is only as good as the closeness with which the rate of ascent is known, and this is almost always within 5 per cent. The effect on the wind aloft is roughly within an error of 5 per cent in the wind speed and the same error in the altitude for which the direction and speed are given. One precaution should be stated here; it sometimes happens that a balloon springs a leak at a certain altitude, and this may cause it to start descending instead of rising at the assumed rate. (See graph 7, fig. 2, p. 213, above.) Since this may not be directly detected by a single theodolite the effect is apparently to increase the distance of the balloon from the instrument, and this in turn magnifies the computed velocity. Therefore, when the single-theodolite method is employed, especial care should be paid to using only very perfect balloons and to see that the neck is sealed tightly before releasing.

A further precaution in the use of balloons is to allow them to stand for a time outdoors subject to current conditions of sun and air, etc., before taking measurements of them, as it has been found that the temperature of a balloon exposed to the sun may be as much as 10° to 20° C. above that of the surrounding air. This causes considerable increase in its size and, therefore, in its lifting power.

In regard to the organization of the military work and the standard methods of operation, it has been found advisable to separate the meteorological stations into two classes— (1) meteorological units for surface data, and (2) aerological units for upper-air data. Meteorological units are further subdivided into those of the first and of the second orders. A first-order meteorological unit is provided with complete meteorological equipment such as is found at regular stations of the U. S. Weather Bureau and is intended to be used at a more or less permanent station only. A second-order meteorological unit possesses only a limited amount of recording apparatus and emphasis is laid upon the portability of the equipment. In like manner, aerological units are divided into two orders—first-order units for two-theodolite work and intended for duty at more or less permanent stations, and second-order units with portable equipment for single-theodolite work. In actual practice combinations of these units are employed, as, for instance, a first-order aerological unit and a first-order meteorological unit are assigned to a permanent station which is to furnish complete data, and aerological and meteorological units both of the second order are assigned to duty at mobile field stations.

For the surface meteorological work the equipment used is all of standard Weather Bureau type, and the forms in use are similar to the corresponding Weather Bureau forms. For aerological work the standard equipment consists of special aircraft theodolites and pilot balloons, as already described. Hydrogen of good purity is used, furnished in steel cylinders having a capacity of 200 cubic feet of gas at a pressure of 1,800 pounds per square inch. For obtaining the lifting power of the pilot balloon, an ordinary balance or scale pan with a set of metric weights is used at permanent stations for accurate work; for a portable field outfit a bronze chain is used with auxiliary weights. The chain is tied to the balloon and from the number of links supported the lifting power is obtained. For single-theodolite work a standard plotting board is employed, the idea of which was originally due to Sergt. 1st cl., E. R. Ryder, Signal Corps. It consists of a transparent celluloid protractor, whose surface is roughened in order to take a pencil mark, which revolves about a pivot in a board covered with cross-section paper. The board is illustrated in figure 4. The method of operation is as follows: By rotating the celluloid protractor, set the azimuth angle for the given reading on the scaled reference line O M; set the arm O R at the elevation angle read on the quadrant protractor on the cross-section paper; find the intersection of the altitude cross-section line (as read on the altitude reference line O N) with the arm O R and follow along the perpendicular cross-section line to the reference line O M and mark the point. This point is the horizontal projection of the location of the balloon for the given reading and the horizontal distance from start may be read from the scaled reference line if desired. This process is repeated for each reading and results in a series of points which determine the horizontal projection of the balloon's path. To obtain the mean wind direction between any two points, set the two points in question so that they lie along the cross-section lines parallel to the reference O M; the direction from which the wind blows is read at P in the units desired. The wind speed may most conveniently be measured by means of a special scale which reads the velocity directly in the units desired. The standard type of two-theodolite boards is an adapted form of this single board and possesses all its advantages. (See figure and discussion, by W. C. Haines and R. A. Wells, below.) Ballistic wind plotting may also be done on the same board at the same time in any convenient portion not in use for plotting the balloon's course.

Meteorological observations on surface conditions are taken at 8 a. m. and 8 p. m., 75th meridian time, and at 12 noon, local time, and whenever balloon ascensions are made. Standard Weather Bureau practice is followed in the procedure. Cloudiness observations are made every two hours from 6 a. m. to 10 p. m. Regular balloon observations are made at 8 a. m. and 4 p. m., 75th meridian time, and whenever locally desired. When continuous reports on the wind aloft are required observations are made every three or four hours. Observations of other character are made whenever desired by departments of the local posts.

All of the meteorological work of the Army has been done in the closest cooperation with the U. S. Weather Bureau. The Weather Bureau furnished all the instrumental equipment used by the Military Meteorological Service during the first few months, and the resources of the Weather Bureau and the counsel of the Chief of the Weather Bureau and his staff have always been available to the Meteorological Section of the Signal Corps and these have been used freely. Without this assistance from the Weather Bureau the early accomplishments of the Military Meteorological Service in the United States would have been of little consequence.

The Meteorological Section of the Signal Corps was under the general supervision of Lieut. Col. R. A. Millikan from the beginning of its organization, during the war, and to December 31, 1918, and under the general supervision of Lieut. Col. John C. Moore since that date.

Much credit is due the enlisted personnel for the work accomplished. Many of these men left responsible positions to become privates in the Meteorological Service. These men not only performed faithfully the work laid out for them to do, but developed new methods and devices for doing the work. It is impracticable to mention individuals by name, because of the large number of men in the service who have accomplished work that would make them worthy of commendation. The personnel was made up mostly of graduate engineers, physicists, mathematicians, and employees of the Weather Bureau.

It should be noted that no mention is made here of the meteorological work done at the actual battle front in France. The Meteorological Section of the Signal Corps had, however, about 15 officers and approximately 300 enlisted men all trained in meteorology and aerology at the front, and it is thought best that the description of the accomplishments of this portion of the Meteorological Section be left to those who have been engaged in the work overseas.[11]

TWO-THEODOLITE PLOTTING BOARD.

By W. C. HAINES and R. A. WELLS.

[Dated: Weather Bureau, Washington, D. C., May, 1919.]

This board (fig. 1) is identical with the one-theodolite board that is now being used in the Weather Bureau (essentially, that shown in fig. 4 opp. page 222), with the additional features of (1) a protractor, centered at B, and (2) an elevation scale, CD, both drawn on the cross-section paper base, and (3) a brass arm attached at the center of the celluloid protractor, A. The celluloid protractor is superimposed on the cross-section paper base, so that its index point, or center, A, is at a distance from the index point, B, of the protractor drawn on the cross-section paper, corresponding to the distances between the two observing stations, or the length of the base line.

The data are plotted in the following manner: The celluloid protractor is held securely with its zero on the south. The brass arm is set at the first minute's azimuth reading indicated by the theodolite at A station. A pencil mark is made on the celluloid protractor at the point where the azimuth reading indicated by the theodolite at B station intersects the brass arm, as determined by the lines of the protractor on the base paper. Each successive minute is plotted in the same manner and the points are numbered 1, 2, 3, etc.

As an example, let us take the data as to elevation angle and azimuths given in Table 1, and find the other data indicated in the table.

TABLE 1.

Station A.—Zero=north.							Station B.—Zero=north.	
Minutes.	Elevation angle.	Azimuth angle.	Distance from A.	Altitude.	Wind direction in degrees.	Wind velocity in meters per second.	Minutes.	Azimuth angle.
1	20.0	310.0	550	200	315	10.5	1	190.0 [315°=S. E.
2	18.1	315.0	1,255	410	324	10.7	2	205.0 324°=S. E.
3	18.5	320.0	1,820	610	336	10.2	3	220.0 336°=S. S. E.]
4	18.5	325.0	2,425	810	....	....	4	240.0.

[11] Now in preparation for a later issue of the REVIEW.—ED.